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(54) **Pleated metal electrode.**

(57) A battery electrode is provided comprising a porous, pleated metal structure, preferably comprising nickel.

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### Technical Field

This invention relates to corrugated metal articles and, more particularly, to a porous, pleated metal article useful as a battery electrode.

### Background Art

Metal electrodes have long been used in a variety of battery applications. Typically, an electrode prepared from a metal should have a high porosity and surface area while maintaining the current-carrying capability of the electrode. Additionally, the electrode should have good dimensional stability when subjected to thermal cycling such as occurs during charge and discharge of the battery. Further, the maximum amount of electrode area should be packed into the smallest volume possible to maximize the high rate charge and discharge capability of rechargeable batteries. This allows down-sizing of conventional battery structures with attendant efficiencies in utilization of space, weight, and the like. Additionally, the electrode should be as uniform in structure as possible to optimize performance. The subject invention is directed to providing an electrode structure with these characteristics.

### Disclosure Of The Invention

In accordance with the subject invention, porous, pleated electrode structures are provided which are pleated to provide the desired height, desired rigidity, and good dimensional stability during charge and discharge or temperature cycling.

The pleated electrode structures in accordance with this invention typically have geometric voids volumes of at least about 80 percent, preferably from about 82 to about 90 percent, and surface areas (determined by BET) of at least about 0.02 square meters per gram, more typically in the range of from about 0.025 to about 0.040 square meters per gram. By "geometric voids volume" is meant the voids volume of the envelope of the corrugated electrode structure, including the open space between the pleats. They may be prepared from a metallic foraminatate structure, for example, woven wire mesh which has been impregnated with fine nickel powder, sintered, and corrugated to desired dimensions. Alternatively, they may be prepared from randomly-laid metallic particles or fibrils of the desired metal, e.g., nickel, silver, etc., or from, for example, sintered metal fibers which have been impregnated with the desired metal powder and subsequently corrugated to the desired dimensions.

### Best Mode For Carrying Out The Invention

The battery electrodes in accordance with the subject invention preferably comprise nickel, either in the form of a foraminatate, e.g., wire mesh structure, sintered metal fibers, or nickel powder which has been impregnated into a porous metal base structure, such as sintered stainless steel metal fibers or stainless steel wire mesh, and then sintered in place.

In any of the forms described above, the foraminatate structure, prior to use as a battery electrode, is in pleated form, preferably by corrugation, as described below, to obtain the requisite high surface area, high geometric voids volume, and structural rigidity.

Typically, the porous metal structures from which the pleated electrodes are formed will have thicknesses in the range of from about 0.002 to about 0.020 inches, more preferably from about 0.005 inches to about 0.010 inches. The structures have pleats with a pleat height typically of from about 0.030 to about 0.375 inches, preferably from about 0.100 to 0.130 inches with the pleat pitch (number of pleats per inch) typically in the range of from about 2 to about 100, preferably from about 2 to 30 pleats per inch, more preferably from about 15 to 25 pleats per inch, most preferably about 20 pleats per inch.

The pleats of the structures in accordance with this invention may be formed by conventional means, most preferably by corrugation although other methods such as pressing, rolling, or the like may also be used. The pleats may take various forms. For example, they may be parallel in a generally sheet-like form. Alternatively, the electrode structure may be generally circular in form with fan-shaped pleats. In another embodiment, they may be formed into cylinders, spirals, or the like. Further, the pleats may themselves be pleated either parallel to the priming pleats or across the primary pleats. The pleats may be curved, tapered, or discontinuous, as well as varying in height over their length.

When a metal powder, such as nickel, is sintered to a base substrate, e.g., sintered stainless steel metal fibers or a wire mesh, the technique disclosed in United States Patent No. 4,562,039, which is incorporated herein by reference, is preferably employed. Basically, the process described in that patent calls for forming a stabilized suspension of the dispersed metal particulate, e.g., nickel, in a fluid medium and applying that stabilized suspension to a foraminatate substrate or support of, for example, a woven wire mesh or sintered stainless steel metal fibers, working the support to fill the openings with the stabilized suspension of the metal powder, heating the filled support to dry the stabilized suspension, preferably compressing the dried, filled support to provide better contact be-

tween adjacent particles, and sintering the compressed, dried, filled support to remove volatile material and diffuse the individual metal particles to the metal support and to each other. As discussed above, in the alternative, the basic foraminata structure when made of the appropriate material, e.g., nickel or sintered metal fibers, may itself be corrugated and used to form the battery electrode.

As an alternative embodiment of the subject invention, a cathode/anode combination structure can be formed with a separator interleaf by forming the anode and cathode of the appropriate foraminata structure and pleating the anode/separator interleaf and cathode together in the manner described above. A typical separator interleaf that may be used in this manner is described in United States Patent No. 4,339,473 which is incorporated herein by reference.

The subject invention may be used with a variety of secondary batteries, including nickel/cadmium, nickel/zinc, nickel/silver, and nickel/iron.

The subject invention will be understood by reference to the following example which is given by way of illustration and not by way of limitation.

A corrugated electrode comprising stainless steel wire mesh and nickel powder was made by the following steps:

1. A stainless steel woven wire mesh with a mesh count of 84 wires per inch by 84 wires per inch with a wire diameter of 0.0035 inches was compressed (calendared) to a thickness of  $0.005 \pm 0.0002$  inches.

2. The compressed woven wire mesh was then impregnated with fine nickel powder in a stabilized suspension with nominal nickel powder particle diameters of approximately 8 microns. The impregnation process used was the same as that taught in U. S. Patent No. 4,562,039. Specifically, a stabilized suspension of the dispersed metal particulate, nickel powder, in a fluid medium was formed by mixing 26.6 parts by weight water, 30 parts by weight of the nickel powder, and 0.269 parts by weight Carbopol 934 (a polyacrylic acid available from B.F. Goodrich Chemicals Company, a molecular weight of 3,000,000), and the stabilized suspension was applied to a foraminata substrate or support of, in this example, a stainless steel woven wire mesh. The support was then worked to fill the openings with the stabilized suspension of the metal powder.

3. After impregnation, the structure was then dried and calendared to a final thickness of  $0.007 \pm 0.0002$  inches thick.

4. The dried structure was then sintered twice at  $2050^{\circ}$  F. in a pure, dry hydrogen atmosphere without the use of setters.

5. After sintering, the structure was corrugated to a pleat height of 0.120 inches with a pitch of 20 pleats per inch.

The corrugated structure exhibited a geometric voids volume of 90% and a BET surface areas of 0.028 square meters per gram. Translating into area, the BET surface area per unit area of the corrugated electrode is 66.4 square meters of surface area per nominal 1 square meter of the corrugated electrode.

Other variations are contemplated including:

1. Inserting conductive and/or non-conductive support and drainage spacers or supports in-between the pleats to further stiffen and rigidify the structure and/or to enhance electrical conductivity properties.

2. Variable pleat pitch per electrode to minimize electrical resistance losses along the length of the electrode and minimize the heat of charge/discharge, e.g., when electrical buss hardware is attached to the top of electrode with the pleats running horizontally, the pleat pitch at the upper portion of the electrode may be higher than in the lower portion.

3. Incorporation of solid metal strips by attaching to the structure, preferably along one or more edges of the structure, prior to sintering or subsequent to sintering and the formation of the pleats in the completed electrode to provide additional stiffness and electrical conductivity. The solid metal strip would also facilitate attachment of electrical buss hardware with minimal electrical resistance.

4. Coining one or more edges of the pleated electrode to stiffen and provide a method to attach the electrode to solid electrical buss hardware by itself or in combination with 1., 2., or 3. above.

Although the present invention has been described in terms of specific exemplary embodiments, it is not limited to those embodiments. Alternative embodiments and modifications which would still be encompassed by the invention may be made by those skilled in the art, particularly in light of the foregoing teachings. Therefore, the following claims are intended to cover any alternative embodiments, modifications, or equivalents which may be included within the spirit and scope of the invention as defined by the claims.

#### Claims

1. A battery electrode comprising a porous, pleated, foraminata metal structure.
2. The battery electrode of claim 1 wherein said metal structure comprises nickel.

3. The battery electrode of claim 1 wherein said metal structure comprises nickel metal powder sintered to a stainless steel wire mesh.
4. The battery electrode of claim 2 wherein said metal structure comprises sintered nickel metal fibers. 5
5. The battery electrode of claim 2 wherein said metal structure comprises stainless steel metal fibers impregnated with nickel powder. 10
6. The battery electrode of claim 2 wherein said metal structure comprises a nickel wire mesh. 15
7. The battery electrode of one of the preceding claims wherein the pleat pitch is in the range of from about 1 to about 100 pleats per inch, particularly wherein the pleat pitch is in the range of from about 2 to about 30 pleats per inch, more particularly wherein the pleat pitch is in the range of from about 15 to about 25 pleats per inch. 20
8. The battery electrode of claim 7 wherein the number of pleats per inch varies along the electrode. 25
9. The battery electrode of one of the preceding claims wherein the pleats include conductive drainage spacers and supports in-between the pleats. 30
10. The battery electrode of one of claims 1 to 8 wherein the pleats include non-conductive drainage spacers and supports in-between the pleats. 35
11. The battery electrode of one of the preceding claims wherein the porous, corrugated, foraminate metal structure includes at least one solid metal strip along at least one edge of the structure. 40
12. The battery electrode of one of the preceding claims wherein at least one of the edges of the electrode is coined. 45
13. The battery electrode of one of the preceding claims wherein the pleats are of a pleat height of about 0.030 to about 0.375 inches, particularly wherein the pleats are of a pleat height of about 0.100 to about 0.130 inches. 50
14. A battery electrode in accordance with one of the preceding claims wherein said metal structure comprises nickel metal powder sintered to a stainless steel wire mesh, and the corruga-

tions provide pleats of a pleat height of from about 0.100 to about 0.130 inches and with a pleat pitch of from about 15 to about 25 pleats per inch.

15. A battery electrode set comprising, in combination, a first porous metal layer, a separator interleaf, and a second porous metal layer wherein the layers as described above are pleated together, in particular wherein one of said porous metal layers is as defined in one of the preceding claims.



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## EUROPEAN SEARCH REPORT

Application Number

EP 92 11 2250

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	DE-A-2 639 881 (PAUL KRAFT)  * page 2, paragraph 1 -paragraph 6 * * page 3, paragraph 5; claim 12; figures 6,9 *	1-5, 11, 15	H01M4/80 H01M4/70 H01M4/24
X	US-A-3 759 747 (G. R. SCHAEER)  * column 3, line 70 - line 71; claims 1,3,7; figure 2; table 2 *	1,2,7, 11,13,15	
X	DE-A-2 438 286 (DEUTSCHE AUTOMOBILGESELLSCHAFT MBH) * page 3, paragraph 3; claim 6; figure 2 *	1	
A	FR-A-2 130 110 (SVENSKA ACKUMULATOR AGIEBOLAGET JUNGNER) * page 4, line 27 - line 28 * * page 6, line 18 - line 20 * * page 6, line 28 - line 31; figure 3 *	1,2	
A	PATENT ABSTRACTS OF JAPAN vol. 8, no. 213 (E-269)28 September 1984 & JP-A-59 098 463 ( SHINKOUBE DENKI KK ) * abstract *	1,2	TECHNICAL FIELDS SEARCHED (Int. Cl.5)  H01M
The present search report has been drawn up for all claims			
Place of search <b>THE HAGUE</b>		Date of completion of the search <b>05 NOVEMBER 1992</b>	Examiner <b>ANDREWS M.P.</b>
<b>CATEGORY OF CITED DOCUMENTS</b>  X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document  T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ----- & : member of the same patent family, corresponding document			

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